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A Summary of the NBS Literature Reviews on the Chemical Nature and Toxicity of the Pyrolysis and Combustion Products from Seven Plastics: Acrylonitrile-Butadiene-Styrenes (ABS), Nylons, Polyesters, Polyethylenes, Polystyrenes, Poly(Vinyl Chlorides) and Rigid Polyurethane Foams

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
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June 1986

Sponsored in part by:

The U.S. Consumer Product Safety Commission
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COMBUSTION PRODUCTS FROM SEVEN
PLASTICS: ACRYLONITRILE-BUTADIENE-
STYRENES (ABS), NYLONS, POLYESTERS,
POLYETHYLENES, POLYSTYRENES, POLY(VINYL
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Table of Contents

	Page
Abstract	1
1.0 Introduction	2
2.0 Scope	3
3.0 Thermal Decomposition Products	4
4.0 Toxicity	9
5.0 Conclusion	13
6.0 Acknowledgements	14
References	15

List of Tables

	Page
Table 1. Results of Bibliographic Search	17
Table 2. Thermal Degradation Products	18
Table 3. Test Methods Used to Assess Toxicity of the Thermal Decomposition Products of Seven Plastics	26
Table 4. LC ₅₀ Values	27

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Abstract

A series of literature reviews was undertaken by the National Bureau of Standards to examine the toxicity and chemistry of the effluents produced when seven plastics were decomposed under various thermal and atmospheric conditions. These plastics are: acrylonitrile-butadiene-styrenes, nylons, polyesters, polyethylenes, polystyrenes, poly(vinyl chlorides), and rigid polyurethane foams. The English language literature on each of these was reviewed and published as a separate report of the National Bureau of Standards. Over 400 different thermal decomposition products, many common to more than one plastic, were identified. The toxicity of most of these individual products is unknown and an assessment of the toxicity of the multitude of possible combinations is not feasible at this time. Therefore, a variety of bioassay toxicity protocols have been used to assess the toxicity of the gaseous atmospheres generated by the thermal decomposition of these plastics. In general, these seven plastics did not produce unusually or extremely toxic pyrolysis or combustion products when compared to those of other synthetic or natural materials. In a few cases involving additives, toxic products of concern were produced.

Keywords: ABS plastics; chemistry; combustion products; literature reviews; nylon; polyester; polyethylene; polystyrene; polyvinyl chloride; pyrolysis products; polyurethane foams; rigid foams.

1.0 Introduction

More people per capita die in the United States and Canada as a result of fires than in any other industrialized nation [1]¹. Eighty percent of these fatalities are attributed to the inhalation of smoke and toxic gases, not to burns [2]. Therefore, the need to determine the degree of toxicity produced from materials thermally decomposed under various fire conditions is evident. In addition, the increased variety of plastics in buildings and homes has raised the issue of whether synthetic materials may produce unusually or extremely toxic combustion products. At least one case has been documented in which a non-commercial fire retarded rigid polyurethane foam produced an unusual toxic combustion product [3]; to a large extent, it was this case which flamed the widespread interest in the field of fire toxicology.

Based on use in consumer products, the Consumer Product Safety Commission (CPSC) prepared a list of the major types of plastics found in residences, where the majority of fire deaths occur. Under joint sponsorship with CPSC, the National Bureau of Standards (NBS) undertook a series of literature reviews to examine the toxicity and chemical identification of the gases produced when seven of the predominant synthetic materials [acrylonitrile-butadiene-styrenes (ABS), nylons, polyesters, polyethylenes, polystyrenes, poly(vinyl chlorides) (PVC), and rigid polyurethane foams] were decomposed under various thermal and atmospheric conditions.

¹ Numbers in brackets refer to the literature references listed at the end of this report.

2.0 Scope

This report summarizes the major findings of reviews of the literature conducted by NBS on the chemical nature and toxicity of the pyrolysis and combustion products of seven plastics: acrylonitrile-butadiene-styrenes (ABS), nylons, polyesters, polyethylenes, polystyrenes, poly(vinyl chlorides) (PVC), and rigid polyurethane foams. For specific details, the reader is referred to these reviews [4-10] and to the original literature referenced therein.

Prior to writing these reviews, a total of ten data bases (Chemical Abstracts, Environmental Abstracts, Excerptica Medica, FRIS Library, Medline, NTIS, RAPRA, RTECS, TRIS, and Toxline) were searched for pertinent publications on ten common plastics (those listed above plus acrylics, phenolics, and polypropylenes). A summary of this literature search, including the number of citations found for each selected plastic in each data base, is shown in Table 1. Recent articles were found through manual searching of current journals and additional references were identified in the bibliographies of the acquired reprints. Following completion of the computer and library searches, detailed reviews were conducted of the research published in English on the seven plastics noted above. Bibliographies and pertinent reprints on the remaining three plastics, acrylics, phenolics, and polypropylenes, were compiled and sent to CPSC, where detailed reviews of these were conducted.

3.0 Thermal Decomposition Products

The thermal decomposition products generated during the pyrolysis or combustion of polymers depend upon their chemical composition, molecular structure, and polymer formulation, which may include a variety of additives, such as plasticizers, stabilizers, flame retardants, cross-linking agents, fillers, and blowing agents. In addition, the conditions of thermal degradation, e.g, temperature, oxygen availability and ventilation, will affect the nature of the generated effluent. The number and type of compounds detected and reported in the literature also depend on the chemical techniques employed and the combustion products of special interest to the investigators performing the studies.

Table 2 shows that over 400 different thermal decomposition products have been measured from these seven plastics and many of these products are common to more than one of the plastics [4-10]. In general, these products were detected through the use of the following analytical techniques: gas chromatography alone or in combination with mass spectrometry, infrared spectroscopy, specific ion electrodes, high pressure liquid chromatography, wet chemical procedures, colorimetric techniques, and colorimetric indicator tubes (Draeger tubes).^{2,3} The absence of a product from this table or from the list for a

² Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the equipment or material identified is necessarily the best available for the purpose.

³ The use of colorimetric tubes, such as Draeger tubes provides unreliable and, at best, semiquantitative results [11].

particular plastic only means that none of the investigators whose work was reviewed detected that compound. Lack of detection may indicate that the compound was not produced under the selected experimental conditions, that the particular analytical techniques were not suitable for that compound, or that the investigator did not specifically analyze for that compound. For example, benzene was found in the combustion atmospheres of all the reviewed plastics except ABS. However, since benzene was one of the reported compounds from polystyrene and ABS contains styrene, it is extremely likely that ABS would also generate benzene.

Knowledge of the chemical composition, molecular structure and formulation of the polymer under study can provide some indication of the gaseous products which may or may not be generated under specified experimental conditions. For example, under vacuum or inert atmospheres,⁴ polymers whose chemical formulation does not include oxygen, e.g., ABSs, polyethylenes, polystyrenes, and PVCs, would not be expected to produce oxygenated thermal degradation products. (In some cases, such products were detected and probably indicate the presence of leaked or trapped air or oxygen-containing additives in the compounds [4,5,6].) On the other hand, polymers containing oxygen in their molecular structure (e.g., polyesters, rigid polyurethane foams, and nylons) would be expected to produce oxygenated volatile gases, such as carbon monoxide (CO) and carbon dioxide (CO₂), even in the absence of oxygen in the

⁴ Examination of materials under oxygen-free conditions does not simulate real fire situations. However, such studies provide information on the generation of thermal decomposition products under controlled experimental conditions and possible effects of vitiated atmospheres which are common in fires. In actuality, many of the products produced under inert atmospheres are also detected in oxidative environments.

atmosphere. ABSs, rigid polyurethanes, and nylons would be expected to produce nitrogen-containing compounds, such as hydrogen cyanide (HCN), regardless of the atmosphere under which they were decomposed; whereas, PVC would not be expected to produce such nitrogenous compounds. As shown in Table 2, some PVCs were found to generate nitrogen-containing products, including HCN. These most likely indicate the presence of a nitrogen-containing additive or possible contaminant. For example, Levin et al. examined a PVC containing zinc ferrocyanide (an additive designed to suppress smoke) which produced large amounts of HCN [9,12]. Hydrogen cyanide has also been detected in the decomposition products of some non-nitrogen-containing PVC copolymers, for example, a vinyl chloride-vinylidene chloride copolymer [13]; therefore, one should be cautious when examining generic materials of unknown formulation. In a similar fashion, based on molecular structure, PVC is the only one of these seven plastics which would be expected to produce chlorinated degradation products. However, widespread usage of halogenated fire retardants in plastic formulations makes predicting materials which will produce halogenated combustion products extremely difficult.

Complete combustion in excess oxygen of a polymer containing carbon, hydrogen, oxygen, and nitrogen yields CO_2 , water (H_2O) and nitrogen dioxide (NO_2). It is during incomplete combustion under various atmospheric conditions in either flaming or non-flaming modes that the many compounds listed in Table 2 are generated. When oxygen is limited, the primary gases formed during the combustion of most materials are CO, CO_2 and H_2O . In addition to CO, which is a major toxicant produced by all seven plastics, other principal thermooxidative products of toxicological concern as noted in these reviews were HCN from

ABSs, nylons, and rigid polyurethane foams; ammonia (NH_3) and NO_2 from nylons; acrolein from polyethylenes; styrene from polystyrenes; and hydrogen chloride (HCl) and benzene from PVC [4-10]. While the toxicity of these chemicals is fairly well documented, the toxicity of many of the other individual compounds listed in Table 2 is unknown.

Temperature plays an important role in influencing the production of decomposition products. In general, as the temperature and thus the rate of decomposition increases, the quantity of the more complex compounds and heavier hydrocarbons decreases and the concentrations of CO and CO_2 increase [4-10]. The generation of HCN has also been shown to increase as a function of temperature [4,7,10]. Another example is HCl , the detection of which begins when stabilized PVC is heated to approximately 200°C ; rapid dehydrochlorination then occurs at 300°C [9]. The evolution of NO_2 also increases with increasing decomposition temperatures [7]. In contrast to these studies, however, more acrolein was generated under lower temperature, non-flaming conditions than under higher temperature, flaming conditions [6].

The presence of fire retardants, either additive or reactive, in plastics can influence the nature of the thermal degradation products. Halogenated products will be generated when chlorine- and bromine-containing fire retardants are used. With the exception of these two statements, it is difficult to make generalizations about the effects of fire retardants on the generation of combustion products and their resultant toxicity (see also Section 4.0). This difficulty arises because, in most cases in the literature, neither the exact formulation of the fire retardant nor that of the plastic has

been specified. In addition, the thermal decomposition conditions between studies are usually so variable that comparison of results is not feasible.

Although large-scale room tests would better simulate real fire situations, most of the reviewed studies have been conducted under small-scale laboratory conditions. The large-scale room burns that were examined for these reviews were usually complicated by the presence of multiple materials and changing fire conditions [7,8]. Both of these factors prevent the assignment of specific combustion products to individual materials or to particular experimental conditions. On the other hand, small-scale tests are performed under a variety of conditions which attempt to simulate different fire scenarios. For example, non-flaming oxidative pyrolysis may represent the early stages of a fire when the oxygen levels are high (>16%) and the heat flux is low. Under these conditions, the gaseous effluents are complex and contain many high molecular weight chemical species. Fires close to flashover can be simulated in flaming tests conducted under higher heat fluxes and possibly low oxygen conditions. In such tests, the combustion products are distinguished by higher concentrations of thermally stable compounds (such as the aromatics) and low molecular weight compounds (such as CO and CO₂).

When single materials are burned in large-scale tests and specific toxicants are examined, such as in the work by Kuhn et al. cited in the review on polyethylene [6], interesting and important information may be obtained. For example, they found that acrolein concentrations in the large-scale tests were too low to be of toxicological concern, whereas CO levels were at least three times the amount needed to kill rats in 30 minutes.

Most of the reviewed studies did not examine the particulate matter which is produced when these materials were thermally decomposed. The smoke particulate and condensable matter are important for two reasons. First, many of the thermal degradation products may condense or be absorbed by the soot particles and be transported with the smoke. Hydrogen chloride is one example of a compound that may be transported in such a fashion or may form a corrosive acid mist in moist air [9]. One study of the particulate matter which formed during the smoldering decomposition of a rigid polyurethane foam showed that many compounds detected in the soot fraction were not found in the volatile fraction [14]. Second, the particulate matter may interfere with the escape and rescue of individuals from burning buildings by causing the obscuration of vision and upper respiratory distress.

4.0 Toxicity

The surveyed literature showed that eight main toxicity protocols plus a number of miscellaneous methods were used to assess the toxicity of the thermal decomposition products from the seven plastics under review (Table 3). These methods are described briefly in the NBS reviews of the individual plastics [4-10]. Detailed descriptions of the methods may be found in the book by Kaplan, Grand and Hartzell [15] as well as in the original literature cited in the NBS reviews.

Two major problems hindered the review and assessment of the extensive toxicological literature on this subject. First, pure materials were generally

not tested. In the majority of cases, materials were given generic designations since their exact formulations were considered proprietary information by their manufacturers. Additives commonly used in plastic formulations, such as plasticizers, smoke suppressants, flame retardants, cross-linking agents, stabilizers, etc., were usually unspecified and, many times, unknown. Therefore, the likelihood of the same material being examined by two or more investigators is extremely low. Only in a few cases, as in the interlaboratory evaluation of the NBS Toxicity Test Method, were the identical materials examined by a number of laboratories. Second, the variations in the test methods were extensive and included different combustion systems, temperatures of decomposition, heat fluxes, animal species, methods of animal exposure, exposure durations, sizes of exposure chambers, types of exposure (dynamic or static), air flow rates, biological endpoints and chemical measurements. Since the generated combustion atmosphere is dependent upon the above factors and the resultant toxicity depends upon the gas concentrations in those atmospheres, toxicological results from different test methods should not be compared.

All the LC_{50} values (regardless of test methods, materials, animal species, exposure times, etc.) for the selected generic classes of materials were compiled in Table 4. The data in this table have to be examined with caution and should be recognized as not being statistically representative. For example, the LC_{50} values range from 3.8 to >320 mg/l and while these values were both obtained with the University of Pittsburgh test method, the exposure times were different (i.e., 30 min vs 10 min). Therefore, it would be incorrect to assume the first material was two orders of magnitude more toxic

than the second.

There are no safe combustion atmospheres; they are only more or less toxic when compared to those generated by other products or combinations of products. Materials, therefore, can be classed in reference to each other or to a specific material (Douglas fir and other species of wood have been extensively used in the published literature for this purpose.) Toxicologists have traditionally distinguished materials or compounds as being toxicologically significantly different when their biological figures of merit differ by an order of magnitude [16].⁵ Alarie and Anderson, for example, have used this approach in designing their classification scheme for materials [17].

The toxicological data obtained in this series of reviews were analyzed to determine if any of these seven plastics produce unusually or extremely toxic thermal degradation products when compared to those produced by other materials manufactured for the same end use. (For the purpose of this report, unusually toxic refers to those cases where unexpected adverse physiological or biological effects are produced; whereas, extremely toxic refers to those situations where very small amounts of material relative to that from other materials produce measurable toxicity.) This summary will not reiterate the detailed findings which are provided in the reviews [4-10], but rather will concentrate on those materials which have been shown to be of toxicological concern.

⁵ This statement should not be interpreted to infer that the quantitative values obtained within a test method are also statistically significant only if they differ by an order of magnitude. The statistical significance between values within any one test method should be determined by each investigator in his laboratory. He will most likely find it is less than an order of magnitude.

The thermal degradation or combustion products of these seven plastics generally do not appear to be unusually or extremely toxic when compared to those produced by other materials under similar laboratory conditions.

However, a few cases, involving additives, do stand out. For example, the case mentioned in the introduction of this summary is a prime example of an unusual toxic thermal degradation product. This product formed from a PAPI/pro-poxylated trimethylolpropane rigid polyurethane foam containing the reactive fire retardant 0,0-diethyl-N,N-bis-(2-hydroxyethyl)aminomethyl phosphonate [10]. The combination of this foam and this fire retardant, when decomposed under non-flaming conditions, produced a highly toxic bicyclic phosphate ester, which caused adverse and unexpected neurological effects in exposed rats.

A smoke suppressant, zinc ferrocyanide, has also been shown to increase the toxicity of materials [9,10,12]. The decomposition products of a rigid polyurethane foam with zinc ferrocyanide were twice as toxic as those found for the foam without this additive [10]. When testing a zinc ferrocyanide-PVC formulation, Levin et al. found that both the non-flaming and flaming decomposition products from a mass loading equivalent to 30 mg/l caused deaths of 100% of the rats exposed for only 10 minutes. Under the same experimental conditions, this PVC formulation without zinc ferrocyanide killed only 8% of the exposed animals [12]. This PVC with zinc ferrocyanide was classified by Alarie and Anderson in their most toxic category, i.e., "much more toxic than wood" [18], as was a polychloroprene which also contained zinc ferrocyanide [17,18]. In both of these cases, the increased toxicity was attributed to the generation of HCN. Neither of these products was ever commercially available.

5.0 Conclusion

The toxicity of the thermal decomposition products from most of the tested synthetic materials that have been reviewed here appears to be comparable to that from other synthetic or natural materials formulated for similar end uses. The existence of the few exceptions, however, generates concern about the possibility that other untested materials or future formulations may produce unusually or extremely toxic thermal degradation products.⁶ Based upon the data presented in the reviewed literature, it is not presently possible to determine the toxicity of the thermal effluents of current products or to predict that of new materials without some form of toxicity testing. **It is, therefore, essential to have a means to assess the acute inhalation toxicity of a material's combustion products.**

Although it was beyond the scope of these reviews to examine total toxic hazard, it is important to realize that it is the toxic hazard generated by a material in a specific end use that must be evaluated before decisions are made as to a material's acceptability for that use. Although toxicity is one of the important factors in a toxic hazard assessment, other factors which must be considered include: the quantity of material, its configuration, the proximity of other combustibles, the volume of the compartments to which the combustion products may spread, the ventilation conditions, the ignition and combustion

⁶ The results presented here refer specifically to the seven plastics reviewed. There is at least one other documented case of a material which was not reviewed and which produces extremely toxic pyrolysis and combustion products [12]

properties of the material(s), the presence of ignition sources, the presence of fire protection systems, and the building occupancy [12].

6.0 Acknowledgements

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Table 1

Results of Bibliographic Search

Materials	Toxline 1966-84	Number of Articles From Each Database										Total
		FRIS Library	Medline 1966-84	RTECS 1979-84	Environmental Abstracts		Excerptica Medica		RAPRA 1972-84	Chemical Abstracts 1972-84		
					1971-84	1964-84	TRIS	1974-84	1972-84			
Poly(vinyl chloride)	70	30	49	0	4	3	3	12	1	42	214	
Polystyrene	22	14	25	1	0	2	0	5	0	5	74	
Nylon	16	10	11	1	0	3	0	2	0	1	44	
Poly- ethylene	29	4	22	1	0	0	0	3	2	0	61	
Phenolics	9	6	18	0	0	1	0	3	2	5	44	
Acrylics	38	4	27	0	8	0	0	12	0	5	94	
ABS	46	3	7	0	0	0	0	0	0	2	58	
Poly- propylene	29	11	17	0	0	0	0	2	0	2	61	
Polyester	21	4	22	0	0	4	0	0	1	11	63	
Rigid Poly- urethane	34	11	82	0	4	2	2	6	0	32	173	
General		10	157		9	1		15	0	3	195	
TOTAL	314	107	437	3	25	16	5	60	6	108	1081	

0 - No articles found to date
 General - Articles which cover more than one plastic.

TABLE 2. THERMAL DEGRADATION PRODUCTS [4-10,13]

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
Acetaldehyde	x	x	-	x	-	x	x
Acetamide	x	-	-	-	-	-	-
Acetic acid	x	x	-	x	-	-	-
Acetone	x	x	-	x	-	-	x
Acetonitrile	x	-	-	-	-	x	x
Acetophenone	-	x	x	-	x	-	-
Acetylene	x	-	-	x	x	-	-
p-Acetyl benzoic acid	-	x	-	-	-	-	-
p-Acetyl vinyl benzoate	-	x	-	-	-	-	-
Acids (-COOH)	-	-	x	-	-	-	-
Acrolein	x	x	x	x	x	-	-
Acrylaldehyde	-	-	-	-	x	-	-
Acrylic acid	-	-	-	x	-	-	-
Acrylonitrile	x	-	x	-	-	x	x
Adiponitrile	-	-	-	-	-	-	x
Aldehydes (total)(HCHO)	-	-	x	-	-	-	-
Alkene	x	-	-	-	-	-	-
Allene	x	-	-	-	-	-	-
Allyl alcohol	-	x	-	-	-	-	-
Allylbenzene	-	-	-	-	x	-	-
Allylic chlorides	-	-	-	-	-	x	-
Ammonia	x	-	-	-	-	-	x
Ammonium carbonate	-	-	-	-	-	-	x
Aniline	x	-	-	-	-	-	-
Aniline hydrochloride	x	-	-	-	-	-	-
Anthracene	-	-	-	x	-	-	-
Benzaldehyde	-	x	x	-	x	x	-
Benzene	x	x	-	x	x	x	x
Benzene + n-methylpyridine	-	-	-	-	-	-	x
Benzoanthracene	-	-	-	x	-	-	-
2,13-Benzofluoranthene	-	-	-	x	-	-	-
1,2-Benzofluorene	-	-	-	x	-	-	-
2,3-Benzofluorene	-	-	-	x	-	-	-
Benzo(a)pyrene	-	-	-	x	-	-	-
Benzo(c)pyrene	-	-	-	x	-	-	-
Benzoic acid	-	x	-	-	x	-	-
Benzonitrile	x	-	-	-	-	-	-
Benzoquinoline	x	-	-	-	-	-	-
Benzyl alcohol	-	-	-	-	x	-	-
Biphenyl	-	x	-	-	-	-	-
Butadiene	x	x	-	x	x	x	x
Butanal	-	-	-	x	-	-	-
Butanaldehyde	-	x	-	-	-	-	-
Butane	-	x	-	x	-	-	x
Butane + Butene	-	-	-	-	-	-	x
n-Butane	-	-	-	-	-	x	-
Butene	-	x	-	x	-	x	x
1-Butene	x	-	-	x	x	-	-
1-Butene-3-yne	x	-	-	-	-	-	-
2-Butene, cis	-	-	-	x	-	-	-
2-Butene, trans	-	-	-	x	-	-	-
Butyraldehyde	x	-	-	-	-	-	-
Butyric acid	-	-	-	x	-	-	-
Butyrolactone	-	-	-	x	-	-	-
C ₂ , C ₃ , and C ₅ species	-	-	-	-	-	-	x

THERMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
C ₄ - C ₁₀	-	-	-	-	-	-	x
C ₉ H ₁₆	-	-	-	-	x	-	-
Caproic acid	-	-	-	x	-	-	-
Caprolactam	-	-	-	-	-	-	x
Carbon dioxide	x	x	x	x	x	x	x
Carbon monoxide	x	x	x	x	x	x	x
C ₄ -Acetaldehyde	-	-	-	-	-	-	x
C ₅ -Acetaldehyde	-	-	-	-	-	-	x
C ₄ -Alcohols	-	-	-	-	-	-	x
C ₂ -benzene	-	-	-	-	-	-	x
C ₅ -Benzene	-	-	-	-	-	-	x
C ₇ -lactam	-	-	-	-	-	-	x
C ₈ -lactam	-	-	-	-	-	-	x
C ₁₁ -lactam	-	-	-	-	-	-	x
C ₁₁ -nitrile	-	-	-	-	-	-	x
Carbon tetrachloride	x	-	-	-	-	-	-
Chlorine	x	-	-	-	-	-	-
Chlorobenzene	x	-	-	-	-	x	-
p-Chlorobenzonitrile	-	-	-	-	-	x	-
Chloroethane	x	-	-	-	-	x	-
Chloroethanol	x	-	-	-	-	-	-
Chloroethylene	x	-	-	-	-	x	-
Chloroisopropanol	x	-	-	-	-	-	-
Chloromethane	x	-	-	-	-	x	-
Chloronaphthalene	-	-	-	-	-	x	-
Chloropropene	-	-	-	-	-	x	-
Chloropropylene	x	-	-	-	-	-	-
Chloropyridine	-	-	-	-	-	x	-
Chlorostyrene	-	-	-	-	-	x	-
Chrysene	-	-	-	x	-	-	-
Cinnamaldehyde	-	-	-	-	x	-	-
Cresol	-	-	x	-	-	-	x
Crotonic acid	-	-	-	x	-	-	-
Cumene	-	-	-	-	x	-	-
Cyanobenzene	-	-	-	-	-	-	x
Cyclobutanone	-	x	-	-	-	-	-
Cycloheptanone	-	-	-	-	-	-	x
Cyclohexadiene	-	x	-	-	-	x	-
Cyclohexane	-	x	-	x	-	-	-
Cyclohexanone	-	x	-	-	-	-	x
Cyclohexanonoxime	-	-	-	-	-	-	x
Cyclohexene	-	x	-	x	-	x	x
Cyclopentadiene	-	-	-	-	-	x	x
Cyclopentane	-	-	-	-	-	x	-
Cyclopentanone	-	x	-	-	-	-	x
Cyclopentene	-	x	-	-	-	x	x
2-Cyclopentylidinecyclopentanone	-	-	-	-	-	-	x
2-Cyclopentylcyclopentanone	-	-	-	-	-	-	x
Cyclopropane	-	-	-	x	-	-	-
Decadiene	-	-	-	-	-	-	x
Decanal	-	-	-	x	-	-	-
Decane	-	-	-	x	-	-	-
Decene	-	-	-	-	-	-	x
1-Decene	-	-	-	x	-	-	-
Decylnitrile	-	-	-	-	-	-	x

THERMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPV</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
Diacetyl benzene	-	x	-	-	-	-	-
4,4'-Diamino dimethyl diphenylmethane	x	-	-	-	-	-	-
4,4'-Diamino diphenylmethane	x	-	-	-	-	-	-
4,4'-Diamino methyl diphenylmethane	x	-	-	-	-	-	-
4,4'-Diamino trimethyl diphenylmethane	x	-	-	-	-	-	-
Diazomethane + diazoethane	-	-	-	-	-	-	x
Dichlorobenzene	x	-	-	-	-	x	-
Dichlorobenzonitrile	-	-	-	-	-	x	-
p-Dichlorobenzonitrile	-	-	-	-	-	x	-
Dichlorobutadiene	-	-	-	-	-	x	-
Dichlorobutylene	-	-	-	-	-	x	-
Dichlorocyclopentene	-	-	-	-	-	x	-
Dichloroethane	x	-	-	-	-	-	-
Dichloroethylbenzene	-	-	-	-	-	x	-
Dichloroethylene	-	-	-	-	-	x	-
Dichlorofluoromethane	x	-	-	-	-	-	-
Dichloropentadiene	-	-	-	-	-	x	-
Dichloropentene	-	-	-	-	-	x	-
Dichloropropene	-	-	-	-	-	x	-
Dichlorotoluene	-	-	-	-	-	x	-
Dihydropyran	x	-	-	-	-	-	-
Dimethylbenzene	-	-	x	-	-	-	x
Dimethyl benzoquinoline	x	-	-	-	-	-	-
2,2-Dimethylbutane	-	-	-	x	-	-	-
Dimethylcyclohexene	-	-	-	-	-	-	x
2,2-Dimethyl-cis-3-hexene	-	-	-	x	-	-	-
3,3-Dimethylheptane	-	-	-	x	-	-	-
2,4-Dimethylhexane	-	-	-	x	-	-	-
2,3-Dimethyl-1-hexene	-	-	-	x	-	-	-
Dimethylloxymethane	-	-	-	-	-	-	x
2,3-Dimethylpentane	-	-	-	x	-	-	-
Dimethylpyridine	-	-	-	-	-	-	x
2,6-Dimethyl quinoline	x	-	-	-	-	-	-
Dimethyl toluidine	x	-	-	-	-	-	-
Dioxane	-	-	-	-	-	x	-
p-Dioxane	-	-	-	-	-	-	x
1,4-Dioxane	x	-	-	-	-	-	-
Diphenyl	-	-	-	-	-	x	-
Diphenylamine	x	-	-	-	-	-	-
Diphenylbutylene	-	-	-	-	-	x	-
Diphenylethane	-	-	-	-	-	x	-
1,3-Diphenylpropane	-	-	-	-	x	-	-
1,3-Diphenylpropene	-	-	-	-	x	-	-
Dipropoxy-one-trimethylolpropane	x	-	-	-	-	-	-
Dipropoxy-trimethylolpropane	x	-	-	-	-	-	-
Dipropoxydiene-trimethylolpropane	x	-	-	-	-	-	-
Dipropoxyene-trimethylolpropane	x	-	-	-	-	-	-
Dipropylene glycol methyl ether	x	-	-	-	-	x	-
Di-tert-butyl methyl phenol	-	-	-	-	-	x	-
Divinyl benzene	-	-	-	-	-	x	-
Divinyl terephthalate	-	x	-	-	-	-	-
Dodecanal	-	-	-	x	-	-	-
Dodecane	-	-	-	x	-	-	-
1-Dodecene	-	-	-	x	-	-	-
Epoxide	-	-	-	x	-	-	-

THEMAL DEGRADATION PRODUCTS (continued)

Compound	RPU	PEST	ABS	FE	PS	PVC	NYLON
Ethanal	-	-	x	-	-	-	-
Ethane	x	x	-	x	x	x	x
Ethanol	x	x	-	x	-	-	x
Ethene	-	x	-	-	-	-	x
Ethylbenzene	x	x	x	x	x	-	-
Ethylbenzene & xylene	-	x	-	-	-	-	-
Ethyl benzoate	-	x	-	-	-	-	-
Ethyl cyclopentene	-	-	-	x	-	-	-
Ethylene	x	x	-	x	x	x	x
Ethylene & Acetylene	-	x	-	-	-	-	-
Ethylene oxide	x	-	-	-	-	-	-
2-Ethyl-1-hexene	-	-	-	x	-	-	-
Ethylmethylbenzene	-	-	x	-	x	-	-
4-Ethyl-1-phospha-2,6,7- trioxabicyclo[2.2.2] octane-1-oxide [bicyclic phosphate ester]	x	-	-	-	-	-	-
4-Ethylquinoline	x	-	-	-	-	-	-
p-Ethyl toluene	-	x	-	-	-	-	-
p-Ethyl vinyl benzoate	-	x	-	-	-	-	-
Ethyl vinyl terephthalate	-	x	-	-	-	-	-
Fluoranthene	-	-	-	x	-	-	-
Fluorene	-	x	-	-	-	-	-
Formaldehyde	x	-	x	x	x	-	x
Formamide	x	-	-	-	-	-	-
Formic acid	-	-	-	x	x	-	-
FREON	x	-	-	-	-	-	-
Furan	-	-	-	x	-	-	-
Heptadecane	-	-	-	x	-	-	-
1-Heptadecene	-	-	-	x	-	-	-
Heptadiene	-	-	-	-	-	-	x
1,3-Heptadiene	-	-	-	x	-	-	-
1,6-Heptadiene	-	-	-	x	-	-	-
Heptanal	-	-	-	x	-	-	-
Heptane	-	-	-	x	-	-	x
2-Heptanone	-	-	-	x	-	-	-
3-Heptanone	-	-	-	-	-	-	x
Heptene	-	-	-	x	-	-	x
1-Heptene	-	-	-	x	-	-	-
Hexadecane	-	-	-	x	-	-	-
1-Hexadecene	-	-	-	x	-	-	-
Hexadecylene	-	-	-	-	-	x	-
Hexadiene	-	-	-	x	-	-	x
1,3-Hexadiene	-	-	-	x	-	-	-
1,5-Hexadiene	-	x	-	x	-	-	-
Hexamethylenediamine	-	-	-	-	-	-	x
Hexamethyleneimine	-	-	-	-	-	-	x
Hexanal	-	-	-	x	-	-	-
Hexane	-	-	-	x	x	-	x
n-Hexane	-	-	-	-	-	x	x
2-Hexanone	-	-	-	x	-	-	x
Hexanitride	-	-	-	-	-	-	x
Hexenaldoxime-octadiene	-	-	-	-	-	-	x
Hexene	-	-	-	x	x	-	x
1-Hexene	-	-	-	x	-	-	-

THERMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
1-Hexene, 2-methyl-1-pentene	-	-	-	-	x	-	-
2-Hexene	-	-	-	x	-	-	-
3-Hexene	-	-	-	x	-	-	-
Hexylamine	-	-	-	-	-	-	x
Hydrocarbons	-	-	-	-	x	-	x
Hydrocarbons(C ₄)	x	-	-	-	-	-	-
Hydrocarbons(C _x H _y)	x	-	-	-	-	-	-
Hydrogen	-	x	-	-	x	-	-
Hydrogen bromide	x	-	-	-	-	-	-
Hydrogen chloride	x	-	-	x	-	x	-
Hydrogen cyanide	x	-	x	-	-	x	x
Hydrogen fluoride	x	-	-	-	-	-	-
Hydroperoxide	-	-	-	x	-	-	-
1-Hydroxy ethyl benzoate	-	x	-	-	-	-	-
Hydroxyvaleric acid	-	-	-	x	-	-	-
Indazole	x	-	-	-	-	-	-
Indene	-	-	-	-	-	x	-
Indole	x	-	-	-	-	-	-
Indoline + caprylic acid	-	-	-	-	-	-	x
Isobutanal	-	-	-	x	-	-	-
Isobutene	x	-	-	x	-	-	-
Isobutylene	-	-	-	x	-	-	-
Isodecane	-	-	-	x	-	-	-
Isononane	-	-	-	x	-	-	-
Isooctane	-	-	-	x	-	-	-
Isoprene	-	-	-	-	-	-	x
Isopropanol	x	-	-	-	-	-	-
Isopropylbenzene	-	-	x	-	x	-	-
Isovaleric acid	-	-	-	x	-	-	-
Isoxazole	x	-	-	-	-	-	-
Methane	x	x	-	x	x	-	x
Methanol	x	-	-	x	x	-	x
Methylacetylene	x	-	-	-	-	-	-
p-Methyl acetophenone	-	x	-	-	-	-	-
Methylantracenes & Methylfluorenes	x	-	-	-	-	-	-
Methyl benzoate	-	x	-	-	-	-	-
3-Methyl benzoquinoline	x	-	-	-	-	-	-
Methylbutadiene	-	-	-	-	-	-	x
Methylbutane & Methylbutylene	-	-	-	-	-	-	x
2-Methylbutane	-	-	-	x	-	-	-
2-Methyl-1-butene	x	-	-	x	-	-	-
3-Methyl-1-butene	-	-	-	x	x	-	-
Methylcaprolactam	-	-	-	-	-	-	x
Methylcyclohexane	-	-	-	x	-	-	-
Methylcyclohexanone	-	-	-	-	-	-	x
Methylcyclohexene	-	-	-	x	-	x	-
Methylcyclopentane	-	-	-	-	-	-	x
3-Methylcyclopentanone	-	-	-	-	-	-	x
Methylcyclopentene	-	-	-	x	-	x	x
2-Methyl-1, 3-dioxane	-	-	-	-	-	-	x
4,5-Methylene phenanthrene	-	-	-	x	-	-	-
2-Methyl-4-ethylhexane	-	-	-	x	-	-	-
Methyl ethyl cyclopentane	-	-	-	-	-	x	-
Methyl ethyl ketone	x	-	-	x	-	-	-
2-Methyl-3-ethyl pentane	-	-	-	x	-	-	-

THERMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
2-Methyl-3-ethyl-2-pentene	-	-	-	x	-	-	-
2-Methylheptane	-	-	-	x	-	-	-
2-Methyl-1-heptene	-	-	-	x	-	-	-
2-Methyl-3-heptene	-	-	-	x	-	-	-
3-Methyl-1-heptene	-	-	-	x	-	-	-
2-Methyl-1-hexene	-	-	-	x	-	-	-
3-Methyl-1-hexene	-	-	-	x	-	-	-
4-Methyl-1-hexene	-	-	-	-	x	-	-
4-Methyl-2-hexene	-	-	-	x	-	-	-
Methyl 1-hydroxyethyl terephthalate	-	x	-	-	-	-	-
Methyl indane	-	-	-	-	-	x	-
Methylmethacrylate	-	-	-	-	-	x	-
Methyl-4,5-methylene phenanthrene	-	-	-	x	-	-	-
2-Methylpentane	-	-	-	x	-	-	-
2-Methyl-1-pentene	-	-	-	x	-	-	-
2-Methyl-2-pentene	-	-	-	x	-	-	-
2-Methyl-3-pentene	-	-	-	-	x	-	-
4-Methyl-1-pentene	-	-	-	x	-	-	-
Methyl-phenanthrene	-	-	-	x	-	-	-
Methylphenol	-	-	-	-	x	-	-
2-Methyl propane	-	-	-	x	-	-	-
2-Methyl propenal	x	-	-	-	-	-	-
2-Methyl-2-propenal	-	-	-	x	-	-	-
2-Methylpropene	-	-	-	x	-	-	-
Methylpyrene	-	-	-	x	-	-	-
2-Methylpyridine	-	-	-	-	-	-	x
Methylquinoline	x	-	-	-	-	-	-
Methylnaphthalene	-	-	-	-	-	x	-
Methylstyrene	-	-	-	-	-	x	-
a-Methylstyrene	-	-	x	-	x	-	-
b-Methylstyrene	-	-	x	-	x	-	-
p-Methyl vinyl benzoate	-	x	-	-	-	-	-
Methyl vinyl ketone	-	-	-	x	-	-	-
Monopropoxy-trimethylolpropane	x	-	-	-	-	-	-
Naphthalene	x	x	-	-	-	x	-
Nitric oxide	x	-	x	-	-	-	-
Nitrogen dioxide	x	-	x	-	-	-	-
Nitrogen oxides	x	-	-	-	-	-	-
1,3-Nonadiene	-	-	-	x	-	-	-
3-Nonadiene	-	-	-	-	-	-	x
Nonanal	-	-	-	x	-	-	-
Nonane	-	-	-	x	-	-	x
Nonene	-	-	-	-	-	-	x
1-Nonene	-	-	-	x	-	-	-
Nonenylcyanide	-	-	-	-	-	-	x
Nonenylcyanide + nononenylcyanide	-	-	-	-	-	-	x
Octadecane	-	-	-	x	-	-	-
1-Octadecene	-	-	-	x	-	-	-
1,3-Octadiene	-	-	-	x	-	-	-
Octanal	-	-	-	x	-	-	-
Octane	-	-	-	x	-	-	x
Octatriene	-	-	-	-	-	-	x
Octene	-	-	-	x	-	-	-
Octene-pyridine	-	-	-	-	-	-	x
1-Octene	-	-	-	x	-	-	-
Olefin	-	x	-	-	-	-	-

THEMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
Oxygen	-	-	-	-	x	-	-
Pentadecanal	-	-	-	x	-	-	-
Pentadecane	-	-	-	x	-	-	-
1-Pentadecene	-	-	-	x	-	-	-
Pentadecylene	-	-	-	-	-	x	-
Pentadiene	-	-	-	x	-	-	x
1,3-Pentadiene	-	x	-	x	-	-	-
1,4-Pentadiene	-	x	-	x	-	-	-
Pentanal	-	-	-	x	-	-	-
Pentane	-	-	-	x	x	-	x
2-Pentanone	-	-	-	x	-	-	-
Pentene	-	x	-	x	x	x	x
Pentene-1	-	-	-	-	-	-	x
1-Pentene	-	-	-	x	-	-	-
2-Pentene	-	-	-	x	-	-	-
4-Pentene-1-ol	-	x	-	-	-	-	-
n-Pentene	-	-	-	-	-	x	-
Phenanthrene	-	-	-	x	-	-	-
Phenanthrene & Anthracene	-	x	-	-	-	-	-
3,8-Phenathroline	x	-	-	-	-	-	-
Phenol	x	x	x	-	x	-	x
Phenyl cyclohexane	-	-	x	-	-	-	-
p-Phenylenediamine	x	-	-	-	-	-	-
Phenyl ethanol	-	-	-	-	x	-	-
Phenylbutane	-	-	-	-	-	-	x
2-Phenyl-2-propanol	-	-	x	-	-	-	-
3-Phenyl-1-propene	-	-	x	-	-	-	-
N- Phenyl P-toluidine	x	-	-	-	-	-	-
Phosgene	-	-	-	-	-	x	-
Pimelonitrile	-	-	-	-	-	-	x
Polycyclic aromatics	x	-	-	-	-	-	-
Propadiene	-	-	-	x	-	-	x
Propanal	-	x	-	-	-	x	-
Propanaldehyde	-	x	-	-	-	-	-
Propane	x	-	-	x	x	x	x
Propanol	-	-	-	x	-	-	-
n-Propanol	x	-	-	-	-	-	-
Propene	-	x	-	-	-	-	x
Propenitrile	x	-	-	-	-	-	-
Propionaldehyde	x	-	-	x	-	-	-
Propionic acid	-	-	-	x	-	-	-
n-Propylbenzene	-	-	x	-	x	x	-
Propyl benzoate	-	x	-	-	-	-	-
Propylene	x	x	-	x	x	x	x
Propylene oxide	x	-	-	-	-	-	-
Pryene	-	-	-	x	-	-	-
Pyridine	x	-	-	-	-	-	x
Pyrole	-	-	-	-	-	-	x
Pyrolidine	-	-	-	-	-	-	x
Quinoline	x	-	-	-	-	-	-
Quinone	-	x	-	-	-	-	-
Styrene	x	x	x	-	x	x	x
a-Styrene	-	-	-	-	x	-	-
Styrene monomer	-	-	-	-	x	-	-
Styrene dimer	-	-	-	-	x	-	-
Styrene trimer	-	-	-	-	x	-	-

THEMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
Styrene tetramer	-	-	-	-	x	-	-
Styrene pentamer	-	-	-	-	x	-	-
Styrene hexamer	-	-	-	-	x	-	-
Styrene heptamer	-	-	-	-	x	-	-
Styrene oxide	-	-	-	-	x	-	-
Tertiary butyl methyl phenol	-	-	-	-	-	x	-
Tetradecanal	-	-	-	x	-	-	-
Tetradecane	-	-	-	x	-	-	-
1-Tetradecene	-	-	-	x	-	-	-
Tetradecylene	-	-	-	-	-	x	-
Tetrahydrofuran	-	x	-	x	-	-	-
Tetrapropoxy-trimethylolpropane	x	-	-	-	-	-	-
Tetrapropoxydiene-trimethylolpropane	x	-	-	-	-	-	-
Tetrapropoxyene-trimethylolpropane	x	-	-	-	-	-	-
Toluene	x	x	-	x	x	x	x
2,4-Toluenediamine	x	-	-	-	-	-	-
Toluene monoisocyanate	x	-	-	-	-	-	-
Toluidine	x	-	-	-	-	-	-
Toluidine hydrochloride	x	-	-	-	-	-	-
N-tolyl butylurethane	x	-	-	-	-	-	-
Trichlorobenzene	-	-	-	-	-	x	-
Trichlorobutylene	-	-	-	-	-	x	-
1,1,2-Trichloroethane	-	-	-	-	x	-	-
Trichloroethyl phosphate	x	-	-	-	-	-	-
Trichloroethylene	-	-	-	-	-	x	-
Trichlorofluoromethane	x	-	-	-	-	-	-
Trichloromethane	-	-	-	-	-	-	x
Trichloropropane	-	-	-	-	-	x	-
Tridecanal	-	-	-	x	-	-	-
Tridecane	-	-	-	x	-	-	-
1-Tridecene	-	-	-	x	-	-	-
Trimethylbenzene	-	-	-	-	-	x	-
Trimethyl benzoquinone	x	-	-	-	-	-	-
2,3,3-Trimethyl-1-butene	-	-	-	x	-	-	-
Trimethylcyclopentane	-	-	-	x	-	x	-
2,2,5-Trimethylhexane	-	-	-	x	-	-	-
Trimethylindole	x	-	-	-	-	-	-
2,2,3-Trimethyl-1-pentane	-	-	-	x	-	-	-
2,3,4-Trimethylpentane	-	-	-	x	-	-	-
Trimethylpentene	-	-	-	-	-	x	-
Trimethylquinoline	x	-	-	-	-	-	-
Trimethyltoluidine	x	-	-	-	-	-	-
Triphenylene	-	-	-	x	-	-	-
Tripropoxy-trimethylolpropane	x	-	-	-	-	-	-
Tripropoxy-one-trimethylolpropane	x	-	-	-	-	-	-
Tripropoxydiene-trimethylolpropane	x	-	-	-	-	-	-
Tripropoxyene-trimethylolpropane	x	-	-	-	-	-	-
Tripropylene glycol methyl ether	x	-	-	-	-	-	-
Undecanal	-	-	-	x	-	-	-
Undecane	-	-	-	x	-	-	-
Undecanitrile + undecenitrile	-	-	-	-	-	-	x
Undecene + undecane	-	-	-	-	-	-	x
1-Undecene	-	-	-	x	-	-	-
Urea	x	-	-	-	-	-	-
Valerolactone	-	-	-	-	-	-	-

THERMAL DEGRADATION PRODUCTS (continued)

<u>Compound</u>	<u>RPU</u>	<u>PEST</u>	<u>ABS</u>	<u>PE</u>	<u>PS</u>	<u>PVC</u>	<u>NYLON</u>
p-Vinyl acetophenone	-	x	-	-	-	-	-
Vinyl benzoate	-	x	-	-	-	-	-
Vinyl chloride	-	-	-	-	-	x	-
Vinylcyclohexene	-	-	-	-	x	-	-
4-Vinyl-1-cyclohexene	-	-	x	-	-	-	-
p-Vinyl toluene	-	x	-	-	-	-	-
p-Vinyl vinyl benzoate	-	x	-	-	-	-	-
Water	x	x	-	x	-	x	x
Xylene	x	-	-	-	-	x	-

X: Compound was detected in the thermal degradation products from the designated material.

-: Compound was not detected

RPU: Rigid polyurethane foam

PEST: Polyester

ABS: Acrylonitrile-butadiene-styrene

PE: Polyethylene

PS: Polystyrene

PVC: Poly(vinyl chloride)

Table 3

Test Methods Used to Assess Toxicity of the
Thermal Decomposition Products of Seven Plastics

<u>Test method</u>	<u>Materials</u>						
	<u>ABS</u>	<u>Nylon</u>	<u>Polyester</u>	<u>Polyethylene</u>	<u>Polystyrene</u>	<u>PVC</u>	<u>Rigid Polyurethane</u>
DIN	X	X	X	X	X	X	X
FAA ^b	-	X	X	X	X	X	-
Japanese ^c	-	X	X	X	X	X	X
NASA/USF ^d	X	X	X	X	X	X	X
NBS ^e	X	X	X	X	X	X	X
Michigan ^f	X	X	-	-	X	X	X
Pittsburgh ^g	X	-	X	-	X	X	X
Utah ^h	-	-	-	-	X	-	X
Misc. ⁱ	-	-	X	X	X	X	-

a - Method developed in response to German Commission of Standards

b - Method developed at the Federal Aviation Administration

c - Includes a variety of test methods developed by Japanese

d - Method developed by National Aeronautic and Space Administration and University of San Francisco

e - National Bureau of Standards test method

f - University of Michigan test methods

g - University of Pittsburgh test method

h - University of Utah test method

i - Miscellaneous protocols: For details, see reviews of each material [4-10]

X - method used

- - Method not used

Table 4

LC₅₀ Values

<u>Material</u>	<u>Test Procedure</u>	<u>Animal Species</u>	<u>Mode</u>	<u>Exposure Time (min)</u>	<u>Post-Exposure Time</u>	<u>LC₅₀ Value (mg/l)</u>	<u>Reference</u>
ABS							
	NBS	rats	F	30	0	15.6-22.1	4
	NBS	rats	F	30	14 days	15.0-28.5	4
	NBS	rats	NF	30	0	22.0-38.0	4
	NBS	rats	NF	30	14 days	19.3-64.0	4
	Pittsburgh ^b	mice	M	30	10 min.	9.3-10.5	4
	Michigan ^a	mice	NI	240	7 days	12.0-22.0	4
ABS/FR	Michigan	mice	NI	240	7 days	13.3-14.0	4
Nylon							
Polyamide	NASA/USF	mice	M	47.5	0	32	7
6	NASA/USF	mice	M	30	0	11	7
yarn	Michigan	rats	M	240	7 days	31	7
fabric	Michigan	rats	M	240	7 days	29	7
6.6	Michigan	rats	M	240	7 days	25	7
knit	Michigan	rats	M	240	7 days	22	7
yarn	Michigan	rats	M	140	7 days	15	7
fabric	Michigan	rats	M	140	7 days	9	7
6.6	Michigan	rats	M	140	7 days	10	7
knit	Michigan	rats	M	140	7 days	11	7
FR	FAA	rats	NI	30	0	86	7
6.6/FR	Michigan	rats	M	240	7 days	25	7
	Michigan	rats	M	140	7 days	11	7
Polyester							
batting	NASA/USF	mice	M	30	14 days	20	8
	Pittsburgh	mice	M	30	10 min.	47	8
fiberfill	NBS	rats	NF	30	14 days	28	8
	NBS	rats	F	30	14 days	31	8
fabric	DIN	rats	NI	30	NI	72	8
	NBS	rats	NF	30	14 days	39	8
	NBS	rats	F	30	14 days	38	8
commercial resin	Pittsburgh	mice	M	30	10 min.	58	8
experimental resin	Pittsburgh	mice	M	30	10 min.	96	8
glass fiber reinforced	Pittsburgh	mice	M	30	10 min.	112	8
	U.S. Testing	rats	NF	30	14 days	122-138	8
	U.S. Testing	rats	NF	30	14 days	63	8
fiber	Japanese	mice	NI	60	7 days	31	8
glass fiber reinforced/FR	DIN	rats	NI	30	NI	48	8
FR	U.S. Testing	rats	NF	30	14 days	76	8
	U.S. Testing	rats	NF	30	14 days	38	8
Halogenated resin	Pittsburgh	mice	M	30	10 min.	24	8

Table 4 (continued)

<u>Material</u>	<u>Test Procedure</u>	<u>Animal Species</u>	<u>Mode</u>	<u>Exposure Time (min)</u>	<u>Post-Exposure Time</u>	<u>LC₅₀ Value (mg/l)</u>	<u>Reference</u>
Polyethylene							
Ethafoam 220	Dow	rats	F	30	14 days	>35	6
	Dow	rats	NF	30	14 days	5.3	6
XFS4100	Dow	rats	F	30	14 days	31.3	6
	Dow	rats	NF	30	14 days	> 6.1	6
wire insulation	NBS	rats	NF	30	14 days	>75	6
	NBS	rats	F	30	14 days	46	6
high density	CMIR	rats	F	30	NI	48.4-51.2	6
	CMIR	rats	NF	30	NI	24.7-25.2	6
Polystyrene							
	Dow	rats	NF	30	14 days	>40	5
	Dow	rats	F	30	14 days	<40	5
	Harvard	rats	NF	20	21 days	>128	5
	Harvard	rats	F	20	21 days	<128	5
	Michigan	rats	M	240	7 days	19.3	5
	Michigan	rats	M	140	7 days	10.2	5
	FAA	rats	NI	30	14 days	>60	5
	USF/NASA	mice	NI	30	--	<24	5
	Pittsburgh	mice	M	30	10 min	16.7	5
FR	Dow	rats	NF	30	14 days	>40	5
	Dow	rats	F	30	14 days	<40	5
	Harvard	rats	NF	20	21 days	<128	5
	Harvard	rats	F	20	21 days	>128	5
	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
High Impact GM 47	GE	rats	NI	120+	14 days	12.0	5
	Utah	rats	NF	30	14 days	>40	5
	Utah	rats	F	30	14 days	27.8	5
	Pittsburgh	mice	M	30	10 min.	9.7	5
GM 49/FR	Utah	rats	NF	30	14 days	>40	5
	Utah	rats	F	30	14 days	35.8	5
	Pittsburgh	mice	M	30	10 min.	16.3	5
GM 51	NBS	rats	NF	30	14 days	>40-50	5
	NBS	rats	F	30	14 days	33.0-53.5	5
	Utah	rats	NF	30	14 days	>40	5
	Utah	rats	F	30	14 days	33.8	5
Styrofoam	Dow	rats	NF	30	14 days	>40	5
	Dow	rats	F	30	14 days	<40	5
Styropor P	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor F 200/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor F 210/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor F 220/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor KR 2180/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor KR 2180/1/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Styropor KR 2180/2/FR	DIN	rats	NF	30	NI	>50	5
	DIN	rats	F	30	NI	<50	5
Pellets	USF/NASA	mice	M	30	0	<240	5
Foam 1	Japanese	mice	NI	15	3 days	>35	5

Table 4 (continued)

<u>Material</u>	<u>Test Procedure</u>	<u>Animal Species</u>	<u>Mode</u>	<u>Exposure Time (min)</u>	<u>Post-Exposure Time</u>	<u>LC₅₀ Value (mg/l)</u>	<u>Reference</u>
PVC							
	NBS	rats	NF	30	14 days	~16	12
	NBS	rats	NF	30	14 days	20	12
	NBS	rats	F	30	14 days	15	12
	NBS	rats	F	30	14 days	17.3	12
Vinyl wall covering	NBS	rats	NF	30	14 days	51.0	19
	NBS	rats	F	30	14 days	39.3	19
	Pittsburgh	mice	M	30	14 days	14.0	19
Conduit	NBS	rats	NF	30	14 days	37.0	19
	NBS	rats	F	30	14 days	29.5	19
	Pittsburgh	mice	M	30	14 days	9.8	19
C-PVC pipe	NBS	rats	NF	30	14 days	9.1	19
	NBS	rats	F	30	14 days	16.0	19
	Pittsburgh	mice	M	30	14 days	4.7	19
Vinyl coated wire	Pittsburgh	mice	M	30	14 days	16.5	19
92% homo-polymer	Pittsburgh	mice	M	30	10 min.	11.7	20
46% homo-polymer	Pittsburgh	mice	M	30	10 min.	25.3	20
PVC ZnFeCN	Pittsburgh	mice	M	30	10 min.	3.8	20
	NBS	rats	NF	30	14 days	7.6-11.3	12
	NBS	rats	F	30	14 days	9.4-15	12
Rigid Polyurethane							
GM 29/30	NBS	rats	F	30	14 days	11.3	10
	NBS	rats	F	30	14 days	13.3	10
	NBS	rats	F	30	14 days	>38.4	10
	Utah	rats	F	30	14 days	11.2	10
	NBS	rats	NF	30	14 days	34.0->39.6	10
	Utah	rats	NF	30	14 days	>40	10
	Pittsburgh	mice	M	30	10 min.	17.3	10
GM 31	Utah	rats	F	30	14 days	14.2	10
	Utah	rats	NF	30	14 days	>40	10
	Pittsburgh	mice	M	30	10 min.	13.7	10
GM 35	Utah	rats	F	30	14 days	12.1	10
	Utah	rats	NF	30	14 days	>36.7	10
	Pittsburgh	mice	M	30	10 min.	12.5	10
GM 37	Pittsburgh	mice	M	30	10 min.	13.3	10
	Utah	rats	F	30	14 days	10.9	10
	Utah	rats	NF	30	14 days	>36.7	10
GM 39	Utah	rats	F	30	14 days	16.6	10
	Utah	rats	NF	30	14 days	10.9	10
RPU	NBS	rats	F	30	14 days	11.0	10
PUR 1	DIN	rats	NF	30	NI	29.0	10
	DIN	rats	NF	30	NI	7.5	10
	DIN	rats	NF	30	NI	6.6	10
PU	Pittsburgh	mice	M	10	5 min.	>320	10
PUA	Pittsburgh	mice	M	10	5 min.	>131	10

Legend for Table 4

a: Reported values converted to mg/l as follows: $\frac{LA_{50} \text{ value (g)}}{1500 \ell^c} \times 10^3 = \text{mg/l}$

b: Reported values converted to mg/l as follows:

$$\frac{LC_{50} \text{ value (g)}}{(\text{Exposure time, min})(\text{dilution air, l/min})} \times 10^3 = \text{mg/l}$$

- c: volume of chamber
- F: flaming
- NF: non-flaming
- NI: not indicated
- M: mixed mode, goes through both non-flaming and flaming conditions
- FR: fire retardant
- CMIR: test developed by Carnegie Mellon Institute of Research
- DIN: method developed in response to the German Commission of Standards
- Dow: test developed by Dow Chemical Company
- FAA: test developed by Federal Aviation Administration
- GE: test developed by General Electric Company
- Harvard: test developed at Harvard University
- Japanese: test developed in Japan
- Michigan: test developed at University of Michigan
- NASA/USF: test developed at University of San Francisco
- NBS: test developed but not necessarily performed at the National Bureau of Standards
- Pittsburgh: test developed at University of Pittsburgh
- U. S. Testing: test developed by U. S. Testing Company
- Utah: test developed at University of Utah

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11. ABSTRACT <i>(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)</i> A series of literature reviews was undertaken by the National Bureau of Standards to examine the toxicity and chemistry of the effluents produced when seven plastics were decomposed under various thermal and atmospheric conditions. These plastics are: acrylonitrile-butadiene-styrenes, nylons, polyesters, polyethylenes, polystyrenes, poly(vinyl chlorides), and rigid polyurethane foams. The English language literature on each of these was reviewed and published as a separate report of the National Bureau of Standards. Over 400 different thermal decomposition products, many common to more than one plastic, were identified. The toxicity of most of these individual products is unknown and an assessment of the toxicity of the multitude of possible combinations is not feasible at this time. Therefore, a variety of bioassay toxicity protocols have been used to assess the toxicity of the gaseous atmospheres generated by the thermal decomposition of these plastics. In general, these seven plastics did not produce unusually or extremely toxic pyrolysis or combustion products when compared to those of other synthetic or natural materials. In a few cases involving additives, toxic products of concern were produced.			
12. KEY WORDS <i>(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)</i> ABS plastics; chemistry; combustion products; literature reviews; nylon; polyester; polyethylene; polystyrene; polyvinyl chloride; pyrolysis products; polyurethane foams; rigid foams.			
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